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RESEARCH MEMORANDUM

PRELIMINARY WIND-TUNNEL INVESTIGATION OF TWO TYPES OF JET-EXIT CONFIGURATIONS FOR CONTROL OF AIRCRAFT

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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PRELIMINARY WIND-TUNNEL INVESTIGATION OF TWO TYPES OF JET-EXIT CONFIGURATIONS FOR CONTROL OF AIRCRAFT

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SUMMARY

Two types of jet controls were investigated in the Lewis 8- by 6-foot supersonic wind tunnel. One type consisted of a converging nozzle which was swiveled at zero and $9^{\circ}40'$ with respect to the flight direction. The other type was a biconvex circular-arc vane mounted in a shroud and placed directly downstream of a convergent nozzle. This vane was tested at angles of attack of zero and 10°. Both type controls were in turn attached to the afterbody of a model of an interceptor-type airplane. The pressure ratio across the nozzle was varied from jet-off to 10 and the free-stream Mach number was set at 1.5 and 1.7.

The normal forces obtained by swiveling the nozzle could be calculated quite closely from simple trigonometric relations. Some discrepancies were found between experimental results and two-dimensional linearized calculations of the forces on the vanes. These may be caused by nonuniformities and lack of definition of the flow upstream of the vane. Pressure surveys on the shroud of the control vane indicated no influence of vane angle on external aerodynamics of this model. Preliminary study indicated that either of the two controls could be made adequate to supply pitching moments required for a delta-wing interceptor at low speeds.

INTRODUCTION

At take-off and landing speeds or at very high altitudes, the dynamic pressure over the conventional external aircraft control surfaces is quite low. Sizing the external surfaces for adequate control forces at these flight conditions may therefore penalize the airplane over a large portion of its flight path. In these regions of difficult external control, the dynamic pressure in the exhaust jet of reaction-type propulsion systems may appreciably exceed that of the free stream. This may be especially true of future turbojet-powered vertical take-off aircraft and rocket installations which have large ratios of engine

thrust to airplane weight (refs. 1 to 4). It thus appears that considerable advantage may be gained by utilizing the exhaust jet as a means of control.

Information is needed, however, to determine the thrust losses associated with various means of jet control and to determine the extent of interaction between internal and external flow.

In order to gain some insight into these problems, this report presents a preliminary investigation of two types of jet controls attached 3337
to an existing jet-exit model of a supersonic interceptor. One of these controls utilized a vane immersed in the jet stream, whereas the other obtained directional forces by swiveling the exit nozzle. Both configurations were studied at free-stream Mach numbers of 1.5 and 1.7 and over a range of jet pressure ratio of jet-off to 10.

APPARATUS AND PROCEDURE

The jet controls were attached to the afterbody of an existing model of a supersonic delta-wing interceptor. This model was designed so that the wing intercepted the tunnel walls in such a manner that it could duct high-pressure air into the model and also serve as the support struts (fig. 1). The high-pressure air was heated outside the tunnel to 700° R by means of a gasoline preheater to prevent possible condensation effects of the expanding air stream at the model exit. After passing through the wing air passages, the air entered the model plenum chamber (fig. 2) and was directed rearwards toward the exhaust nozzles.

A strain-gage-type balance was located in the forebody of the model fuselage. One side of this balance was rigidly attached to the air plenum chamber, which in turn was fixed to the tunnel walls by means of the wing. The model fuselage and vertical tail were attached to the other side of the balance which was capable of measuring axial and normal forces. The forces exerted by the inner liner and nozzle could either be excluded from or included in the balance measurements by attaching this section to the plenum chamber or to the fuselage as shown in figures 2(a) and (b), respectively. The dashed lines of this figure indicate the components attached to the measuring side of the balance, whereas the solid lines designate components rigidly attached to the tunnel.

Various static-pressure taps were located inside the nose and the region between the internal liner and external fairing to correct for extraneous forces resulting from these regions being at pressure other than free stream.

The jet-control vane configuration consisted of a biconvex circular-arc airfoil of rectangular plan form mounted in a shroud and placed directly downstream of a converging nozzle (fig. 3(a)). This arrangement was equivalent to mounting a vane in an ejector which had no secondary flow and had a ratio of internal shroud diameter to nozzle throat diameter of 1.46 and a spacing ratio (distance between shroud exit and nozzle exit divided by nozzle throat diameter) of 1.14. The vane had an aspect ratio of 2.05 and a thickness ratio of 0.12. The lift and drag forces of the vane were transmitted to the balance through the arrangement of figure 2(a).

The swiveled-nozzle configuration (fig. 3(b)) consisted of a converging nozzle, which was rotated about a point approximately 1/2 throat diameter upstream of the exit by removing a V-shaped section and rewelding the components. No attempt was made to build a mechanically movable model. The outer shroud was not swiveled but was cut along a plane perpendicular to the nozzle axis to permit rotation of the nozzle. In this investigation the nozzle and inner liner (fig. 2(b)), as well as the fuselage and tail, were attached to the measuring side of the balance since the jet-control force in this case would be primarily on the nozzle. The balance therefore measured external drag as well as the internal drag of the nozzle, which is equivalent to the change of momentum of the fluid passing through the nozzle and inner liner. Subtracting this change of momentum from the axial component of momentum in the plenum chamber resulted in the axial component of momentum at the nozzle exit; that is, a measure of the nozzle thrust. The axial component of momentum at the plenum chamber was obtained by calibration of 26 static-pressure taps in the end plates of this chamber. The axial force data for the swiveled-nozzle investigation are therefore reported as the thrust at the nozzle exit minus the drag of the external model surfaces.

Total pressure at the nozzle entrance was obtained from continuity relations, measurements of wall static pressure at this station, total temperature measured in the plenum chamber, total weight rate of flow obtained from the orifice meter (fig. 1), and a rotameter to measure fuel flow through the preheater. Twelve static-pressure taps were located on the external surfaces of the shroud of the vane configuration and eight on the external surface of the shroud of the swiveled-nozzle configuration to measure the influence of the various internal flows on external forces.

The control-vane configuration was studied with vane settings of zero and 10°, and the swiveled-nozzle configuration was studied at nozzle settings of zero and $9^{\circ}40'$ with respect to the free-stream direction. These angular settings as well as the vane size were determined by preliminary calculations to satisfy pitching moment requirements of an interceptor-type airplane during conventional take-off. The basic nozzles before swiveling or incorporating vanes were existing exit components from a previous series of tests.

The model was alined in the tunnel so that the axis of symmetry of the exhaust duct approaching the nozzles was along a free-stream direction.

The major portion of the force data presented in this report has been made dimensionless by dividing it by the free-stream static pressure p_0 times the throat area A_* of the nozzle. The control forces are mainly equivalent to changes of internal momentum; these quantities, when divided by p_0A_*, become functions only of the ratio of total to static pressure at the station considered if the ratio of specific heats is held constant. 3337

SYMBOLS

The following symbols are used in this report:

A cross-sectional area

$\bar{c}$ mean aerodynamic chord of wing

C_m pitching moment coefficient, $Nl/Sq_0\bar{c}$

C_p pressure coefficient, $(p - p_0)/q_0$

D drag

F gross thrust at nozzle exit, equal to momentum at nozzle exit minus p_0A_*

l distance from jet control to airplane center of gravity

M Mach number

N force normal to flight direction, positive when directed upward

P total pressure

p static pressure

q dynamic pressure, $\frac{\gamma}{2} pM^2$

S wing area

α_m maximum airplane angle of attack at which jet control can trim airplane

γ ratio of specific heats

δ vane setting, deg

ϵ nozzle setting, deg

Subscripts:

f fuselage

s swiveled nozzle

v vane

σ shroud

0 free stream

1 internal flow station immediately ahead of nozzle entrance

$*$ nozzle throat

DISCUSSION

Jet Vane

Normal force. - The total force of the vane and of the airplane fuselage normal to the free-stream direction $(N_f + N_v)/p_0A_*$ as a function of nozzle pressure ratio P_1/p_0 is shown in figure 4. The normal force of the configuration with a vane setting δ of zero is a result of the asymmetry of the fuselage. The normal force due to a 10° vane deflection can be obtained by subtracting out this fuselage lift. Within the accuracy of the data, the resulting normal force of the vane is shown to vary linearly with nozzle pressure ratio and to be independent of free-stream Mach number.

Inspection of the external static-pressure taps on the shroud surrounding the vane and nozzle indicated no noticeable difference of circumferential pressure distribution between vane deflections of zero and 10°. Varying the angle at which a jet leaves a conventional nozzle, however, was found to affect the pressures on the rear portion of the external fairing of a nozzle configuration when immersed in a free stream (ref. 5). These pressure changes were found to be due to aspiration effects and also to shock interactions caused by deflection of the external stream when intersecting the jet stream. It thus appears for the case of the jet vanes that the jet stream was quite closely returned to an axial direction near the trailing edge of the control vane, so that no difference of deflection of the internal air between the top and bottom surfaces of the jet was obtained even with the vane at 10° deflection.

Included also in figure 4 is the theoretical normal force due to vane deflections calculated by use of two-dimensional linearized theory (ref. 6). This theoretical vane force was added to the normal force of the fuselage (for line $\delta = 0$) to obtain the dashed or theoretical line for $\delta = 10^{\circ}$. When this theoretical normal force was computed, the static pressure immediately upstream of the vane was assumed equal to that measured in the annular passage between the nozzle and boattail walls. This assumption appears quite reasonable for ejectors with no secondary flow and low values of shroud friction. The total pressure at the vane entrance was assumed equal to that at the nozzle entrance. The increase of the theoretical values over that of the experimental values of figure 4 may be largely due to lack of flow definition as well as to a nonuniform flow distribution at the vane location. 3337

Drag force. - Total drag of the model fuselage and jet vane are presented as a function of nozzle pressure ratio P_1/p_0 in figure 5 at a free-stream Mach number of 1.5 and at vane settings of zero and 10°. The "jet-off" line represents the fuselage drag with no jet interference. Interference drags are discussed in references 7 to 9.

Summation of the shroud pressure coefficients times corresponding areas projected normal to the flight direction yielded values of shroud drag coefficient shown in figure 6. Subtraction of the shroud drag at any nozzle pressure ratio from the shroud drag at a jet-off condition ($P_1/p_0 \sim 1$) yields the increment of shroud drag due to jet interference. An appreciable effect of nozzle pressure ratio was found at high pressure ratios; however, no difference of results was observed between vane settings of zero and 10°.

The jet-vane drag of figure 7 was obtained by subtracting the fuselage drag from and adding the jet interference drag reduction to the data of figure 5. These drag values with the vane deflected zero and 10° are equivalent to reductions of 0.5 and 2 percent, respectively, of the thrust of a converging nozzle at a pressure ratio of 4.

Included also in figure 7 is the theoretical vane drag computed by two-dimensional linearized theory (ref. 6). For both vane settings, use of this theory in conjunction with the previously mentioned assumption for predicting vane normal forces underestimated the drag at high pressure ratios and overestimated the drag at low pressure ratios.

Swiveled Nozzle

Normal force. - The forces normal to the flight direction obtained by swiveling the nozzle 9°40' are presented in figure 8 as a function of nozzle pressure ratio at free-stream Mach numbers of 1.5 and 1.7.

The normal force of the fuselage is shown by the line for zero swivel ($\varepsilon = 0$). The normal force due to swiveling the nozzle is indicated by the difference between the square and circular data points. The theoretical increment of normal force due to swiveling the nozzle was added to the fuselage normal force to get the dashed ($\varepsilon = 9^{\circ}40'$) line. This increment was obtained by multiplying the ideal exit momentum of a converging nozzle by the sine of the deflection angle. The theory checks experimental results within the accuracy of the data. The change of normal forces on the shroud due to swiveling the nozzle was found to 3337 be negligible since the shroud was not swiveled (see APPARATUS AND PROCEDURE). No effect of free-stream Mach number on internal performance was found.

Drag force. - The total thrust minus drag of the fuselage and nozzle is presented in figure 9. The axially projected area of the shroud surrounding the nozzle was very small, resulting in a negligible amount of drag change due to jet interference (fig. 6). The ideal thrust of a converging nozzle was added to the total thrust minus drag of the model at the jet-off condition. The resulting values fair quite well through the data and are shown by the line for zero swivel ($\varepsilon = 0$). Simple trigonometric relations (multiplying the ideal thrust of a convergent nozzle by the cosine of the swivel angle) indicate that the theoretical thrust may be reduced 1.5 percent by swiveling the nozzle $9^{\circ}40'$. The accuracy of the data, however, is insufficient to check this result.

Varying the deflection angle ε caused no discernable difference of internal static pressure immediately upstream of the point where the nozzle was swiveled for the same value of weight rate of flow passing through the nozzle. This indicates further that no large loss in total pressure was obtained by swiveling the nozzle.

No influence of the free-stream Mach number increase from 1.5 to 1.7 was observed on internal performance.

Preliminary Evaluation

Results are shown in figure 10 of brief calculations which were made to see if the pitching moments provided by these types of controls are of an order of magnitude sufficient to trim an interceptor-type airplane. A typical schedule of nozzle pressure ratio made available by a turbojet engine, together with the assumption from the foregoing results that internal performance of the controls was independent of external flow, was used in computing the coefficient of pitching moment of the test-model airplane as a function of free-stream Mach number. This pitching moment was corrected for the difference in throat areas of the nozzles of the two controls studied. The maximum angle of attack at which these controls can trim an airplane fairly similar to the one used in this investigation was computed from the data of reference 10.

The coefficient of pitching moment made available by these controls decreased quite rapidly as the free-stream dynamic pressure was increased, resulting also in the rapid decrease of trim angle with free-stream Mach number. It appears that controls of this nature could be made adequate to control pitching moment of this type airplane at low speeds such as take-off; however, for these deflection angles and control sizes, supplementary control would be needed at high speeds.

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SUMMARY OF RESULTS

The normal forces and associated drag penalties of two types of jet controls were investigated over a range of nozzle pressure ratio from jet-off to 10 and at free-stream Mach numbers of 1.5 and 1.7. In both types the control surfaces were deflected zero and approximately 10°. For these ranges of variables, the following conclusions were reached:

1. Normal forces on a jet-control vane computed by two-dimensional linearized theory were somewhat higher than experimental.

2. The drag of the control vane at a deflection of 10° was equal to 2 percent of the thrust of an ideal converging nozzle operating at a pressure ratio of 4.

3. Normal forces on a swiveled-nozzle-type control computed by simple trigonometric relations were in close agreement with experiment.

4. No effects of free-stream Mach number change were found on the behavior of either type of control.

5. No difference of external shroud pressures between the vane deflected zero and 10° was noted.

6. Preliminary study indicated that either of the two controls could be made adequate to supply pitching moments required for conventional take-off of an interceptor.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, June 14, 1954

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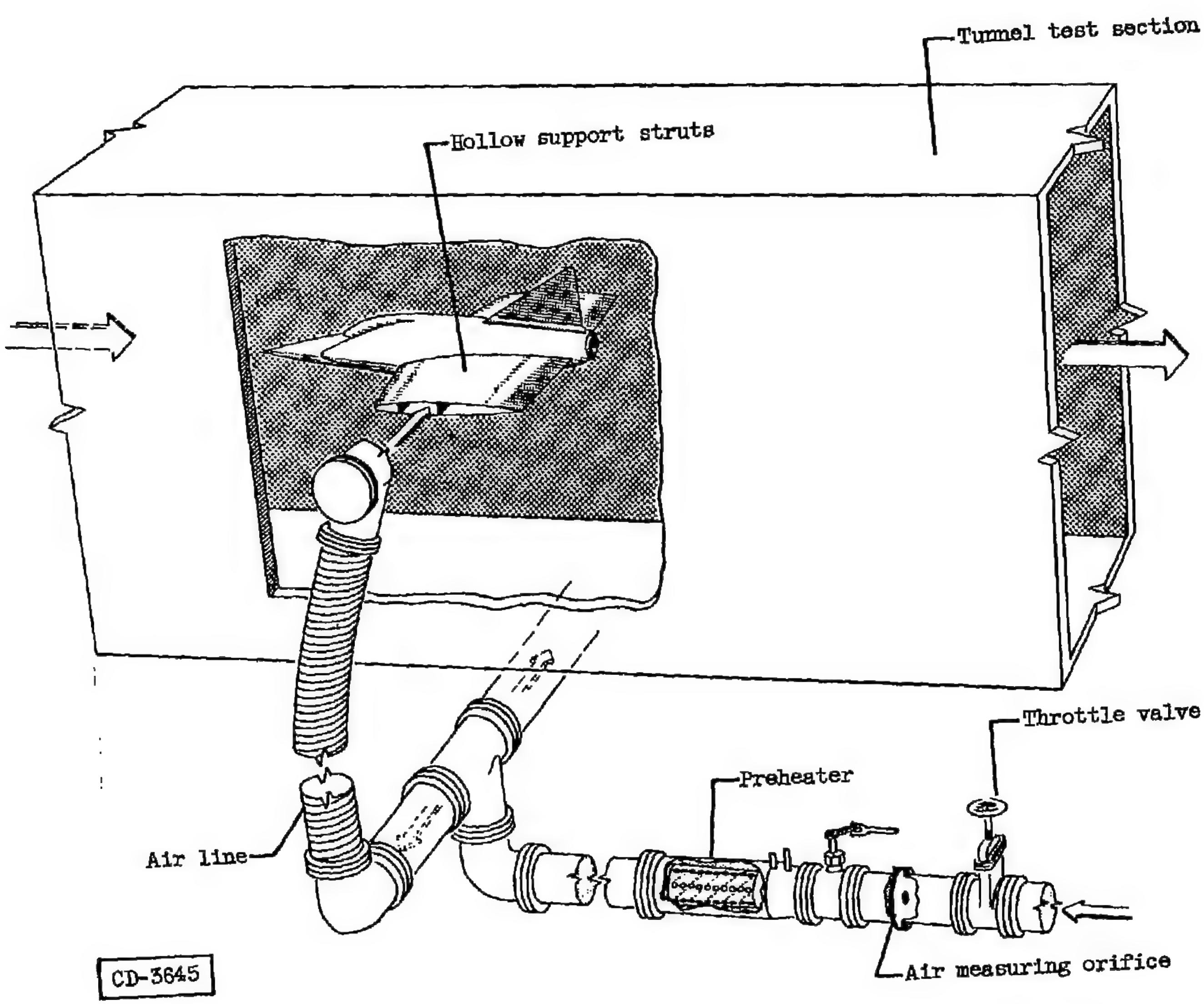

Figure 1. - Schematic drawing of model in 8- by 6- foot supersonic wind tunnel.

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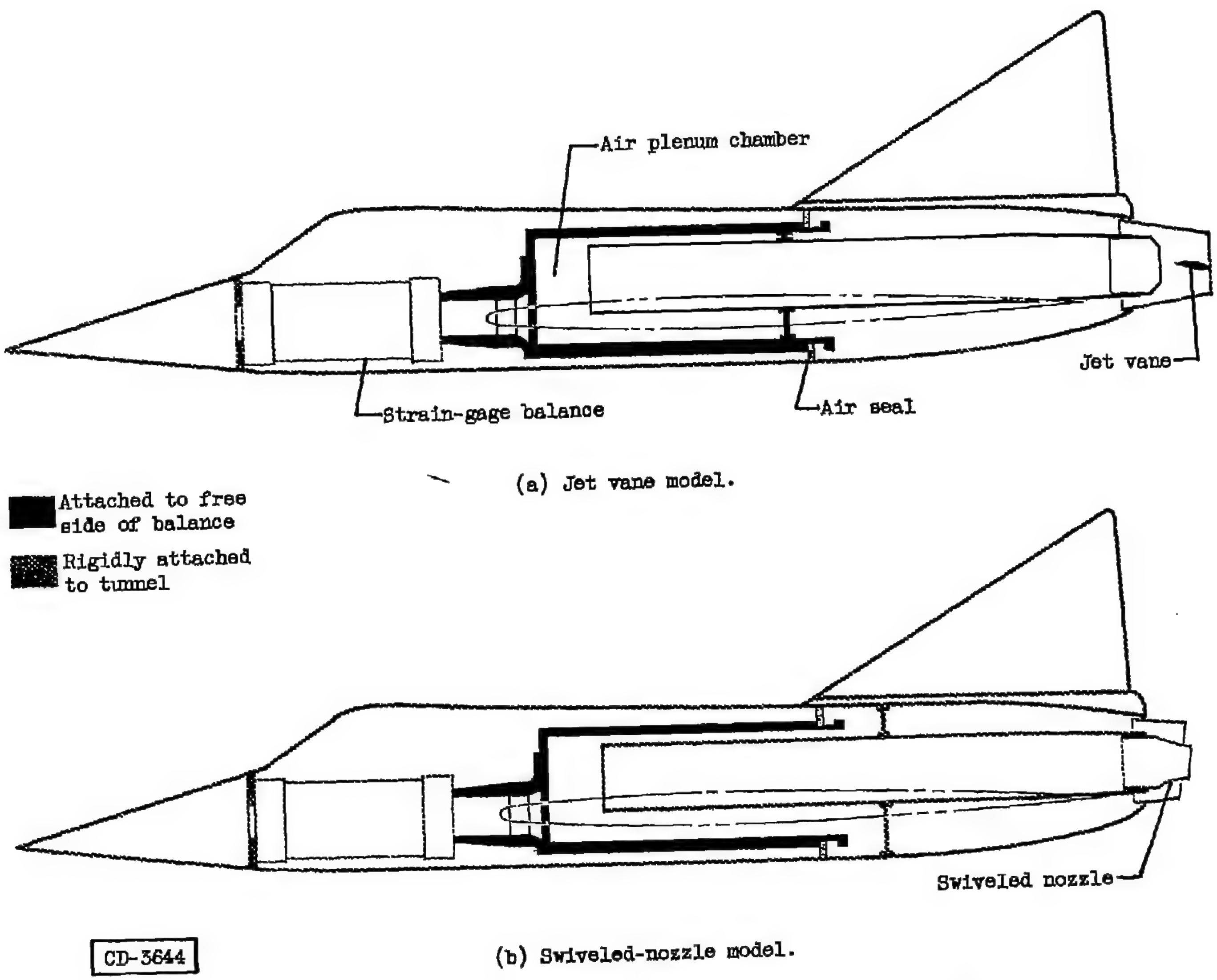

(a) Jet vane model.

(b) Swiveled-nozzle model.

Figure 2. - Schematic diagram of component attached to balance.

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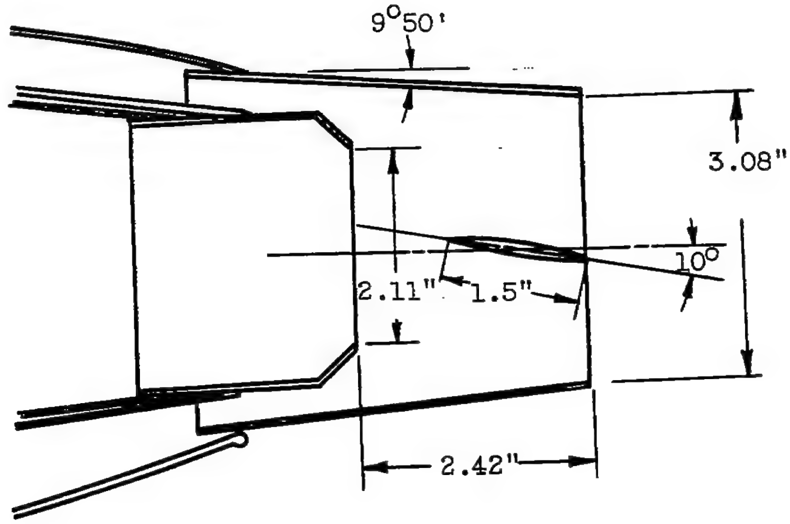
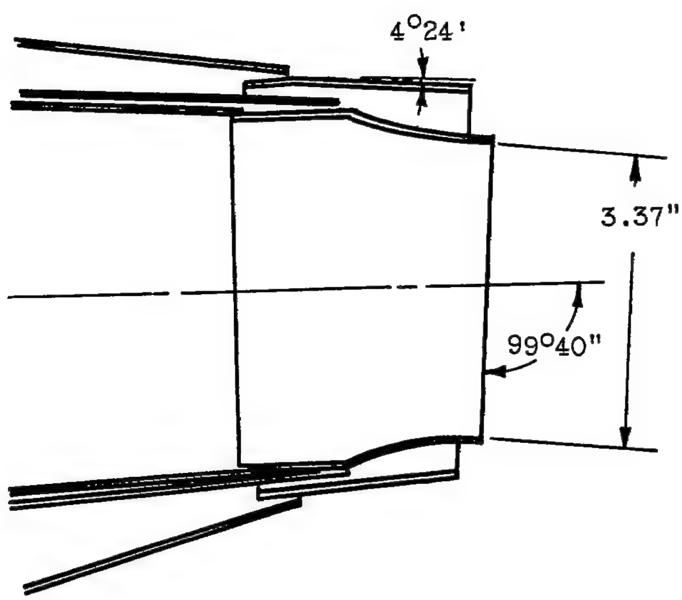


(a) Control by jet vane.



(b) Control by swiveled nozzle.

Figure 3. - Two types of jet control.

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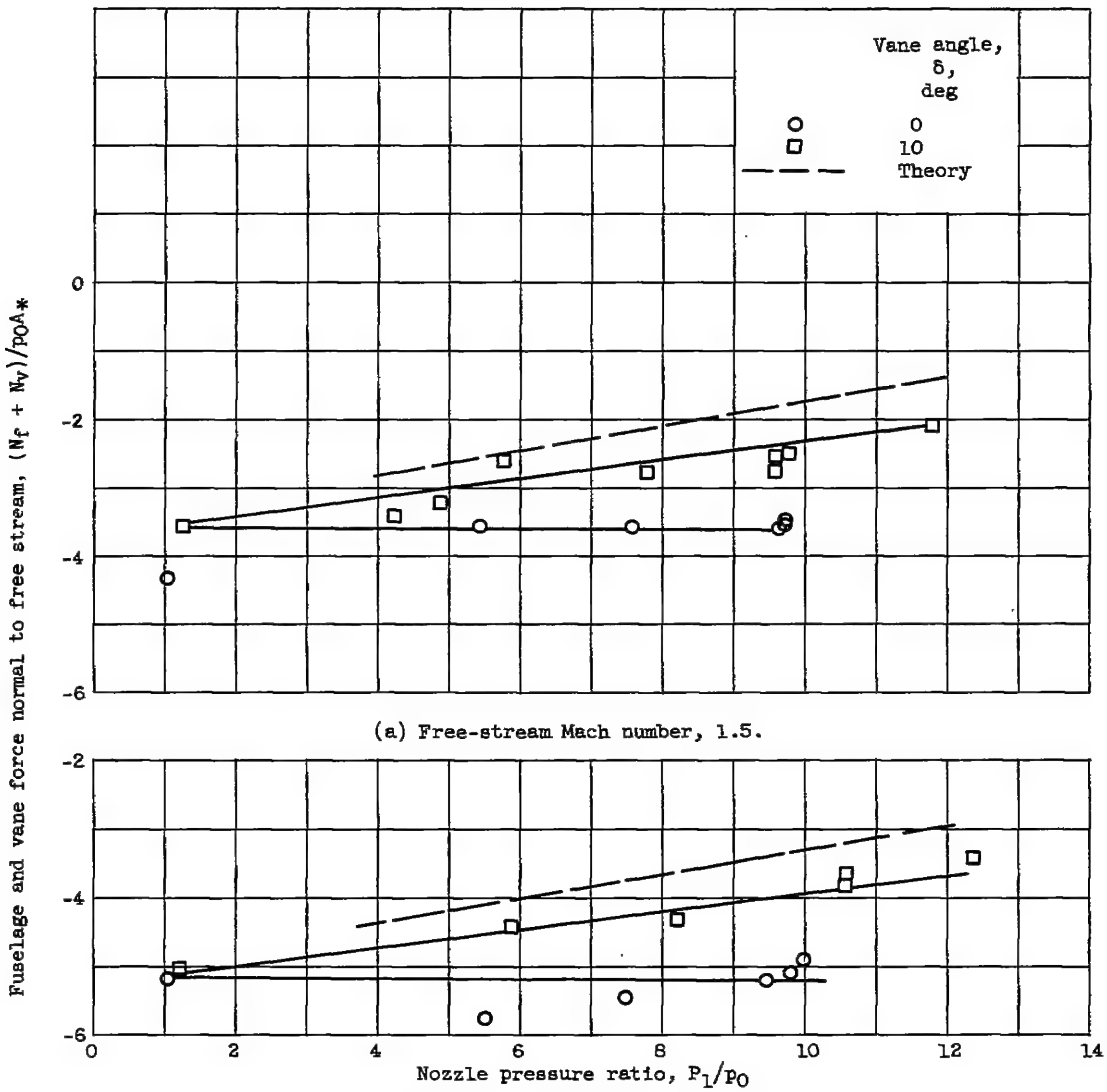

(b) Free-stream Mach number, 1.7.

Figure 4. - Combined forces of fuselage and control vane normal to free stream.

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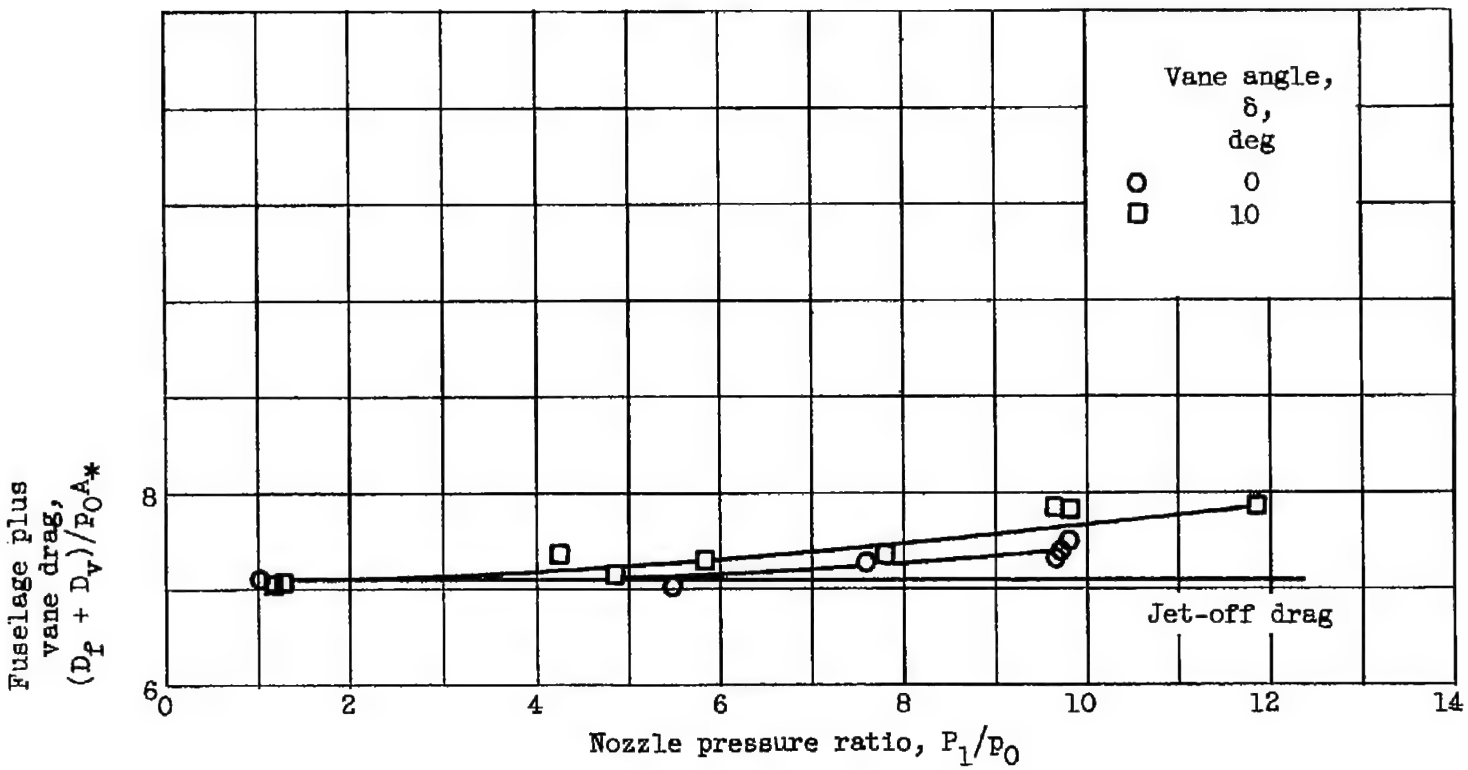

Figure 5. - Balance measurements of fuselage and control-vane drag. Free-stream Mach number, 1.5.

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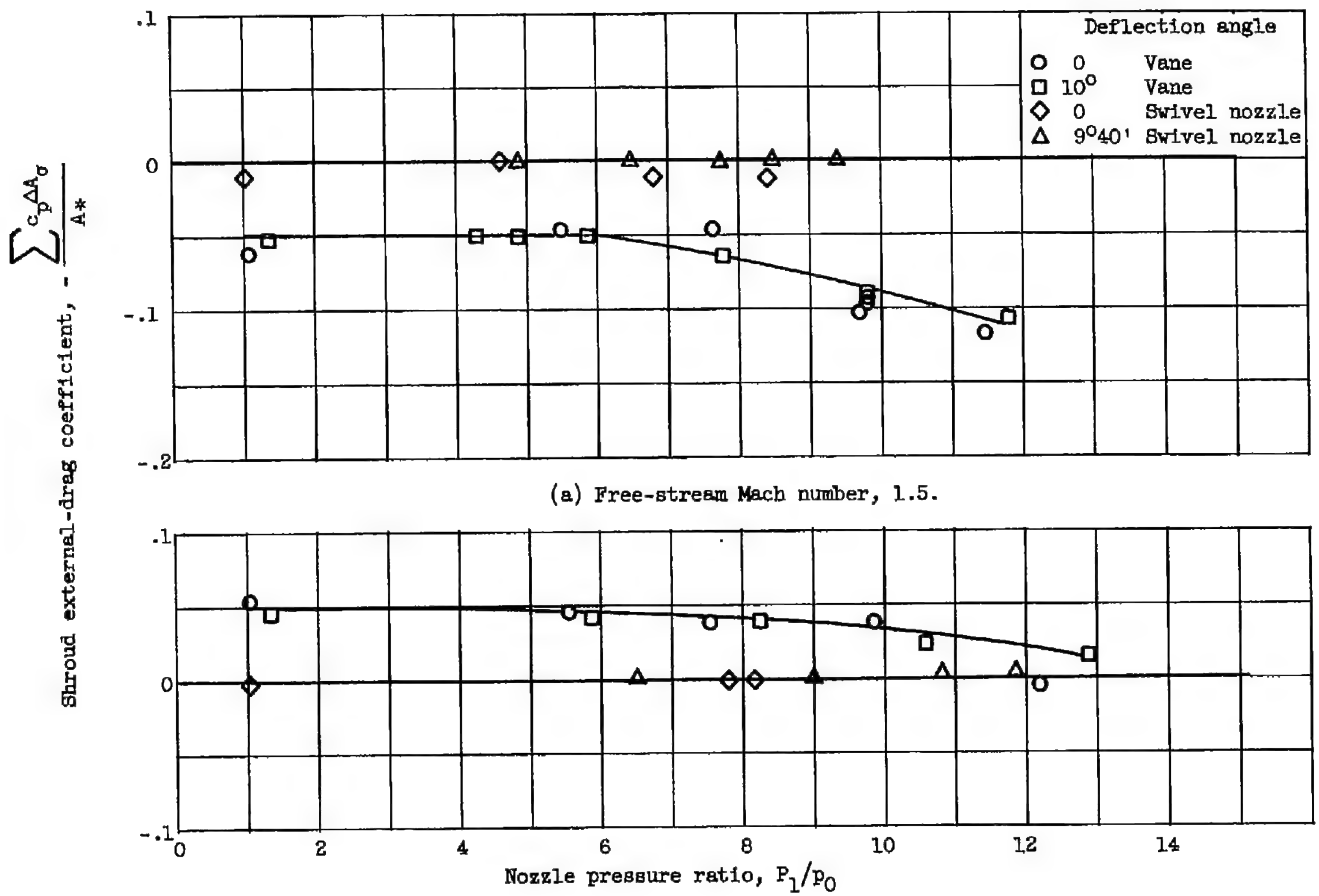

(a) Free-stream Mach number, 1.5.

(b) Free-stream Mach number, 1.7.

Figure 6. - Effect of deflection angle on external pressure drag of shroud.

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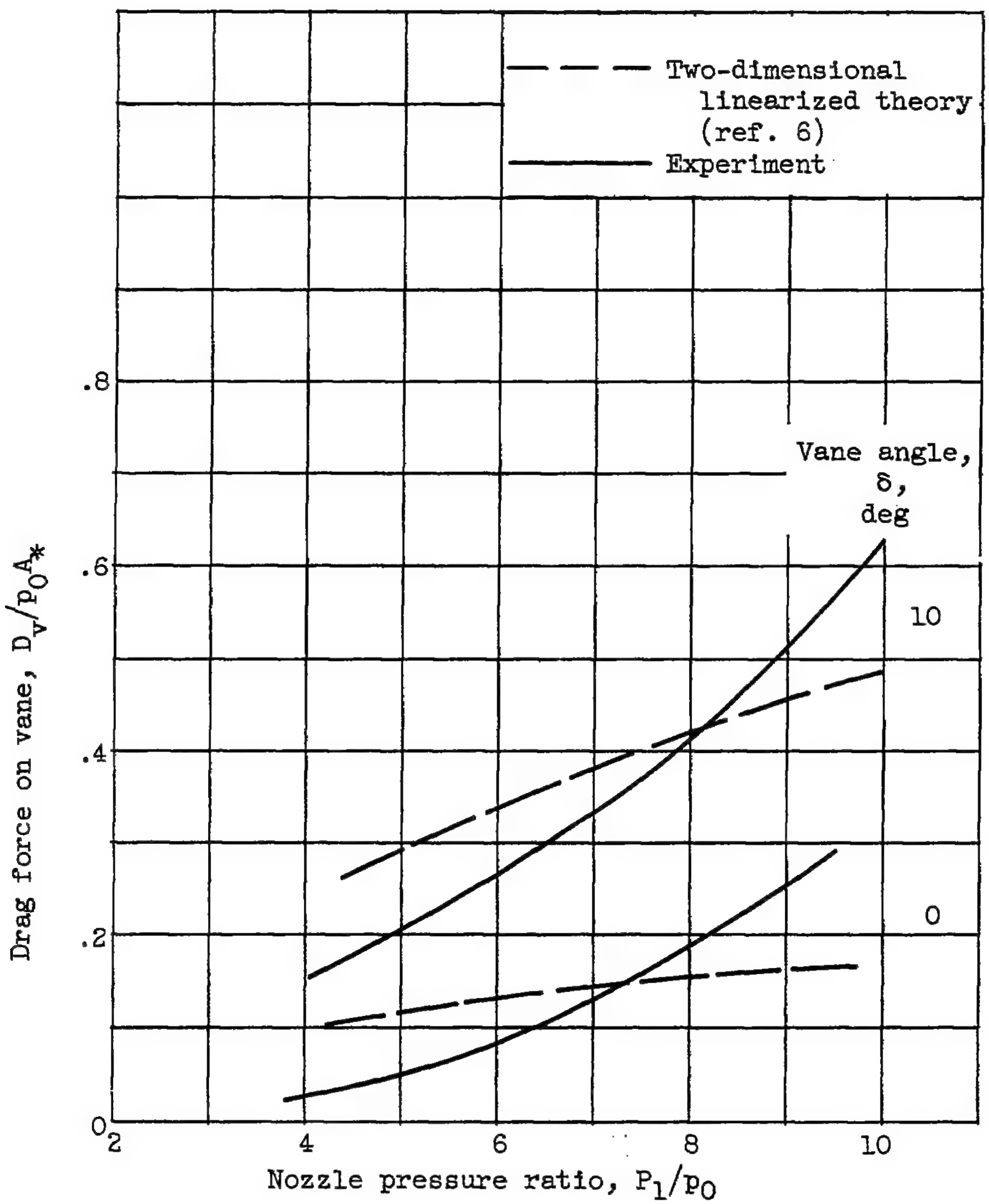

Figure 7. - Drag force on vane. Free-stream Mach number, 1.5.

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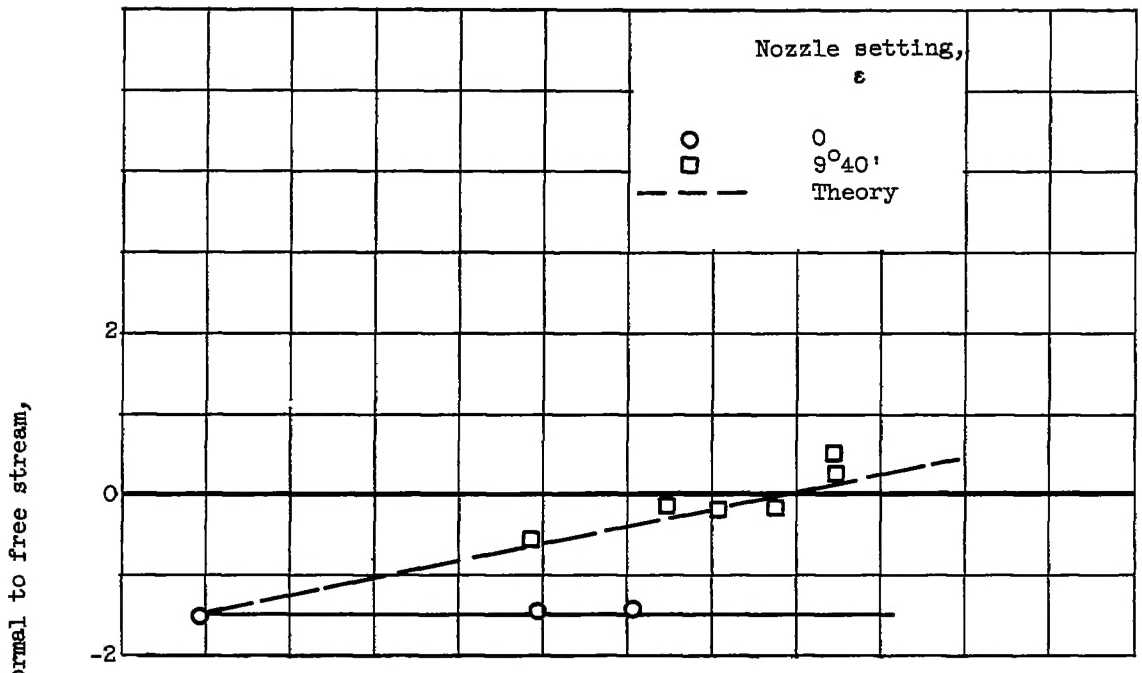
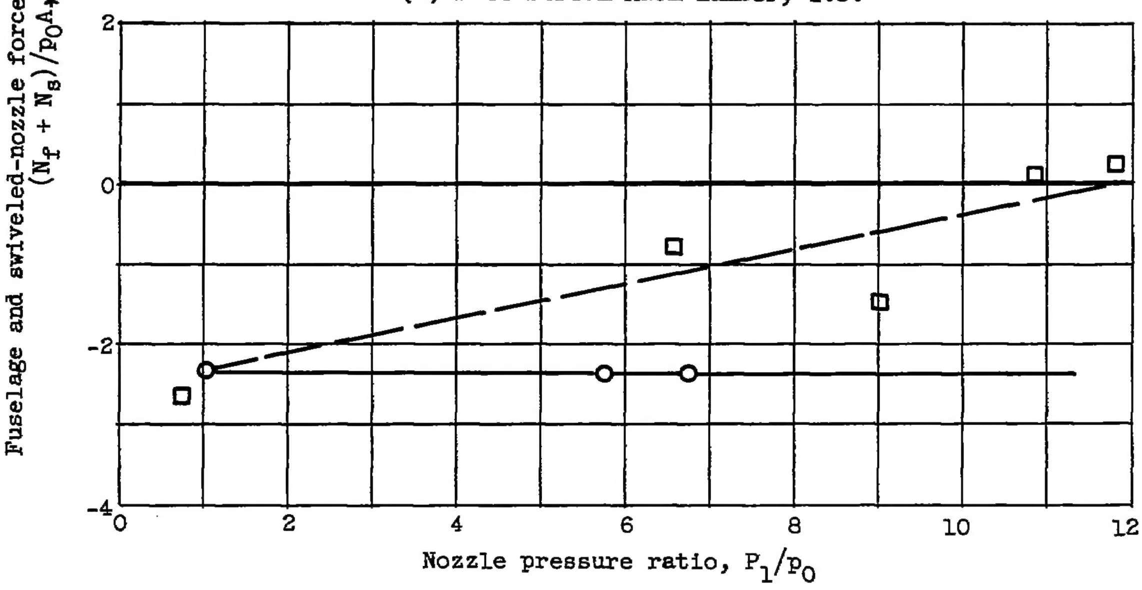
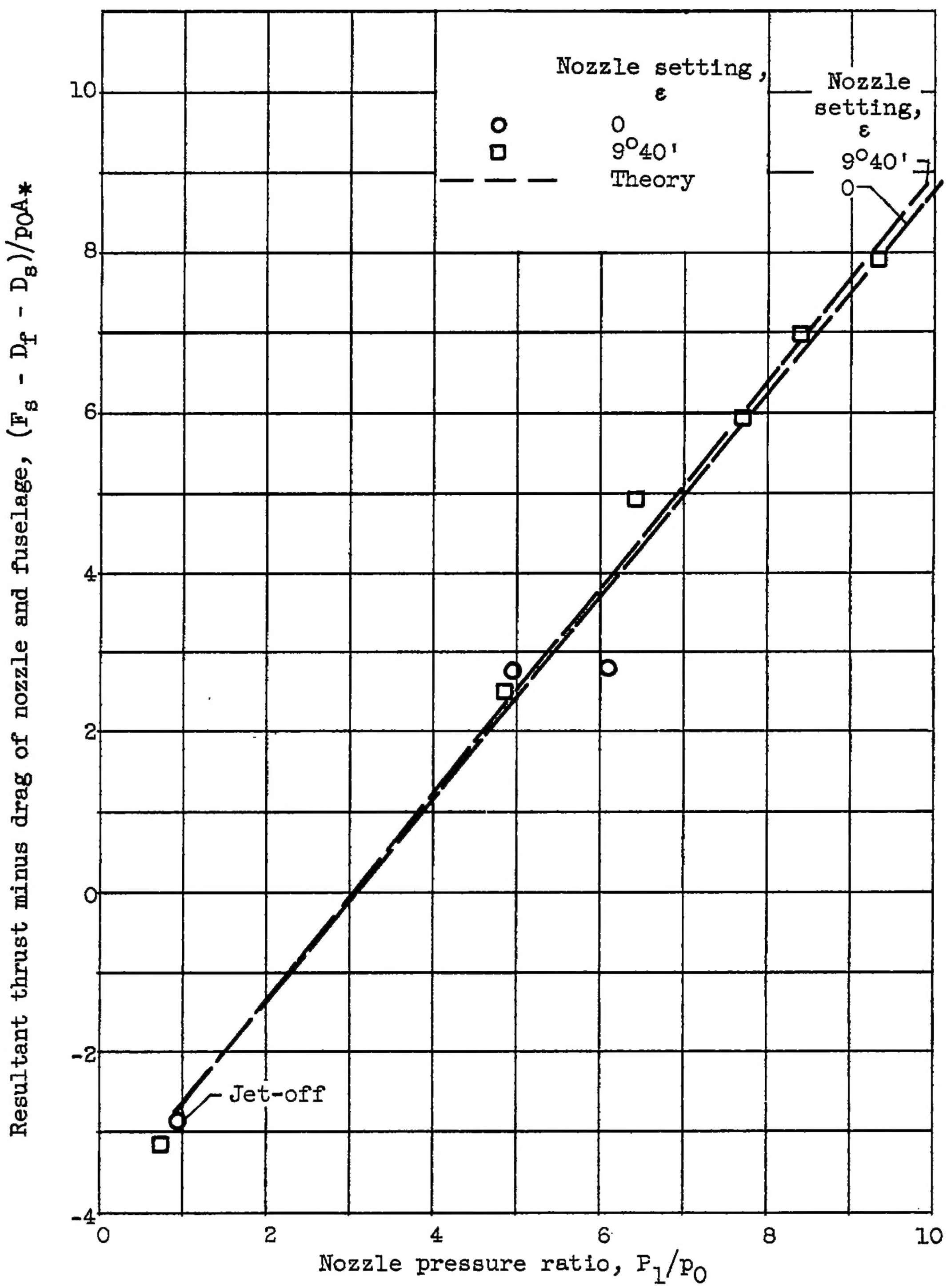


(a) Free-stream Mach number, 1.5.



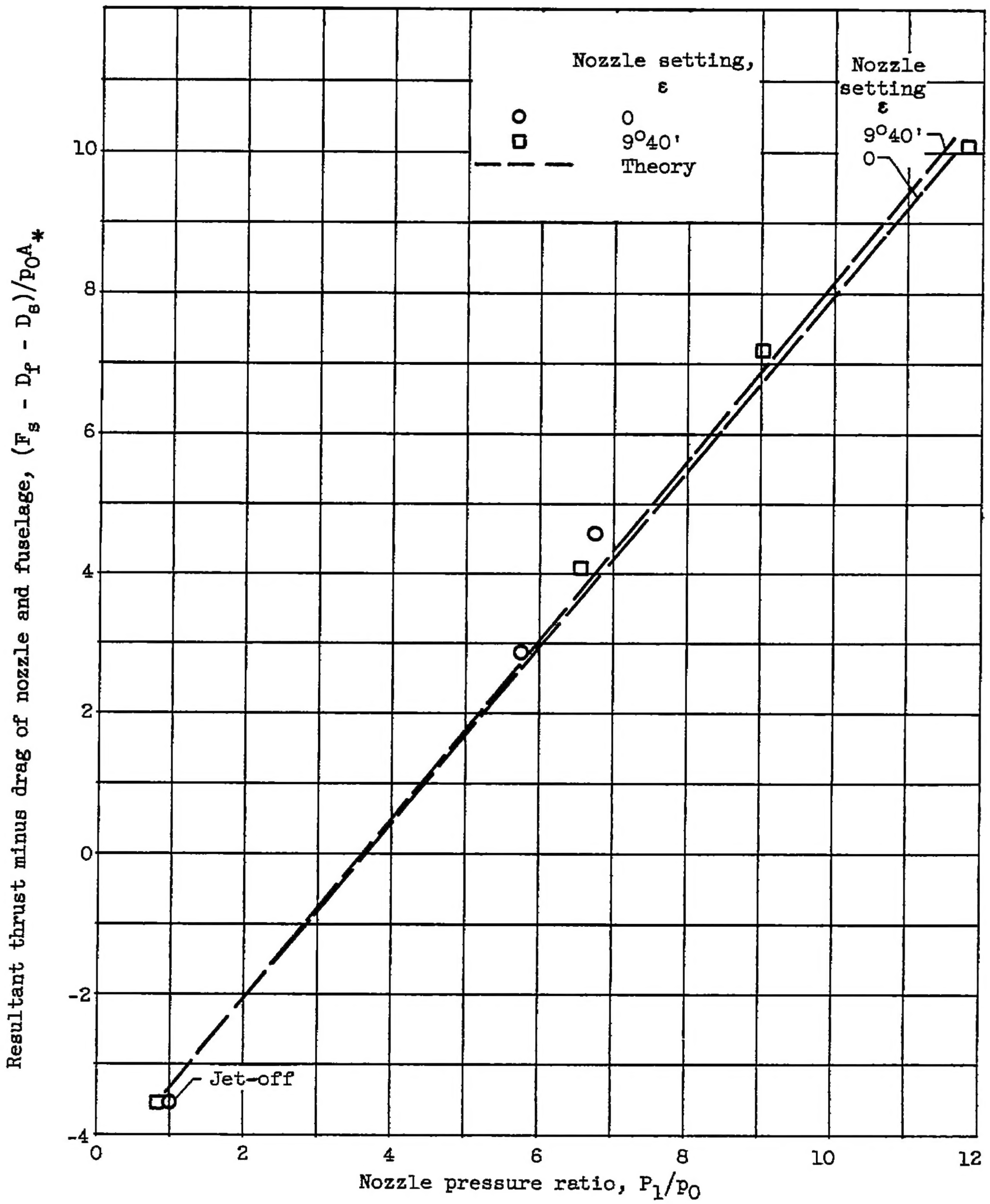
(b) Free-stream Mach number, 1.7.

Figure 8. - Combined forces of fuselage and swiveled nozzle normal to free stream.



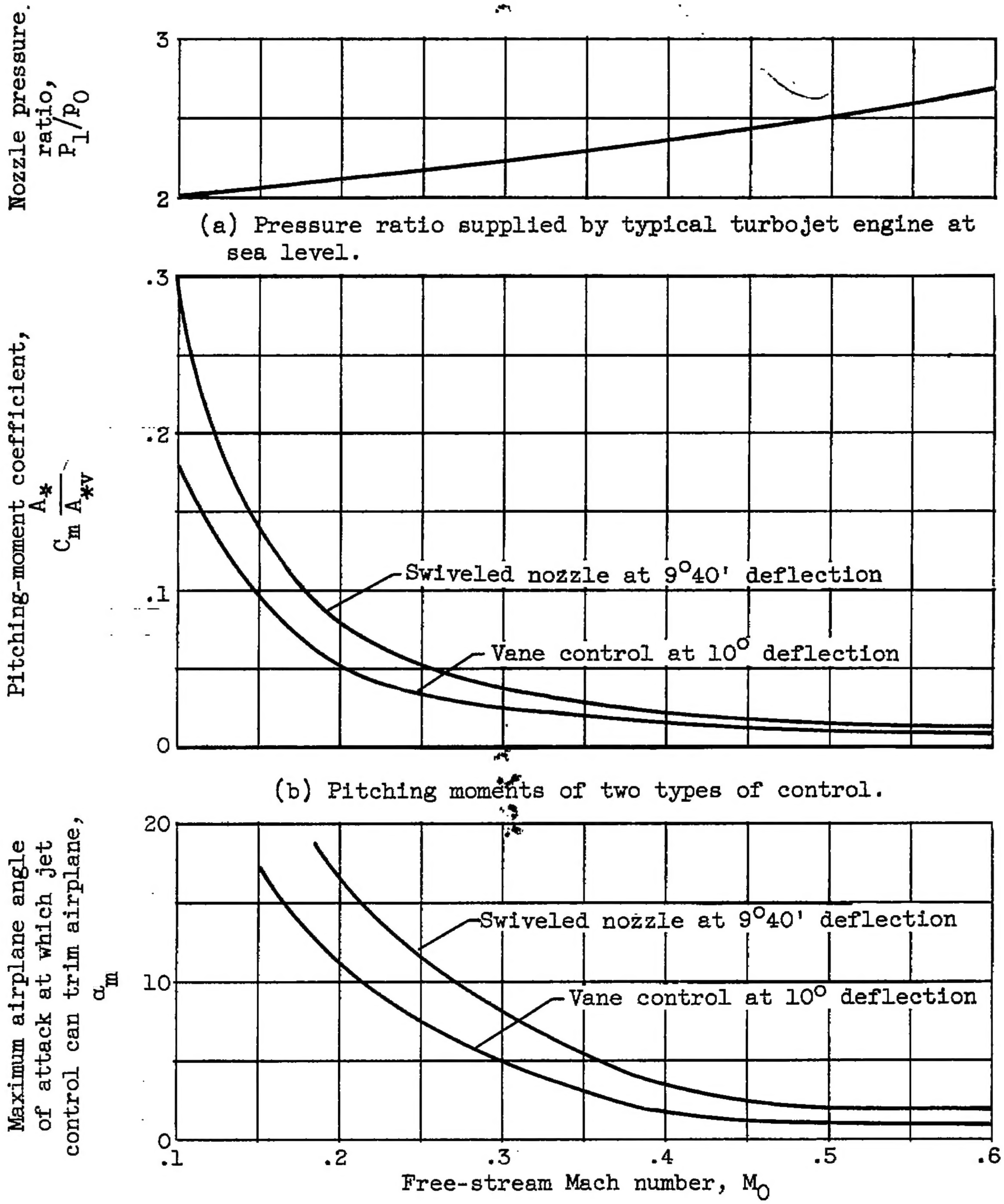
(a) Free-stream Mach number, 1.5.

Figure 9. - Resultant axial force of complete model.



(b) Free-stream Mach number, 1.7.

Figure 9. - Concluded. Resultant axial force of complete model.



(a) Pressure ratio supplied by typical turbojet engine at sea level.

(b) Pitching moments of two types of control.

(c) Adequacy of above moments to control typical delta-wing airplane.

Figure 10. - Application of jet controls to an airplane at low speeds and sea level.

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